DOE-ARRA Geologic Sequestration Training and Research
2011 Yearly Review Meeting

Project DE-FE0002224
Title: Geologic Sequestration Training and Research

University of Alabama at Birmingham
Southern Company

Presenter: Peter Walsh
Department of Mechanical Engineering, UAB

February 23, 2011

Project Participants

- Peter Walsh, Principal Investigator,
  Research Professor, Dept. of Mechanical Engineering, UAB

- Richard Esposito, Senior/Key Co-Investigator,
  Principal Research Geologist, Southern Company

- Konstantinos Theodorou, Graduate Research Assistant,
  Ph.D. Candidate, Interdisciplinary Engineering, UAB

- Michael Hannon, Graduate Research Assistant,
  Ph.D. Candidate, Interdisciplinary Engineering, UAB

- Aaron Lamplugh, Undergraduate Research Assistant,
  Global and Community Leadership Honors Program, UAB

Introduction

Seal Layers Control Upward Migration of CO_2

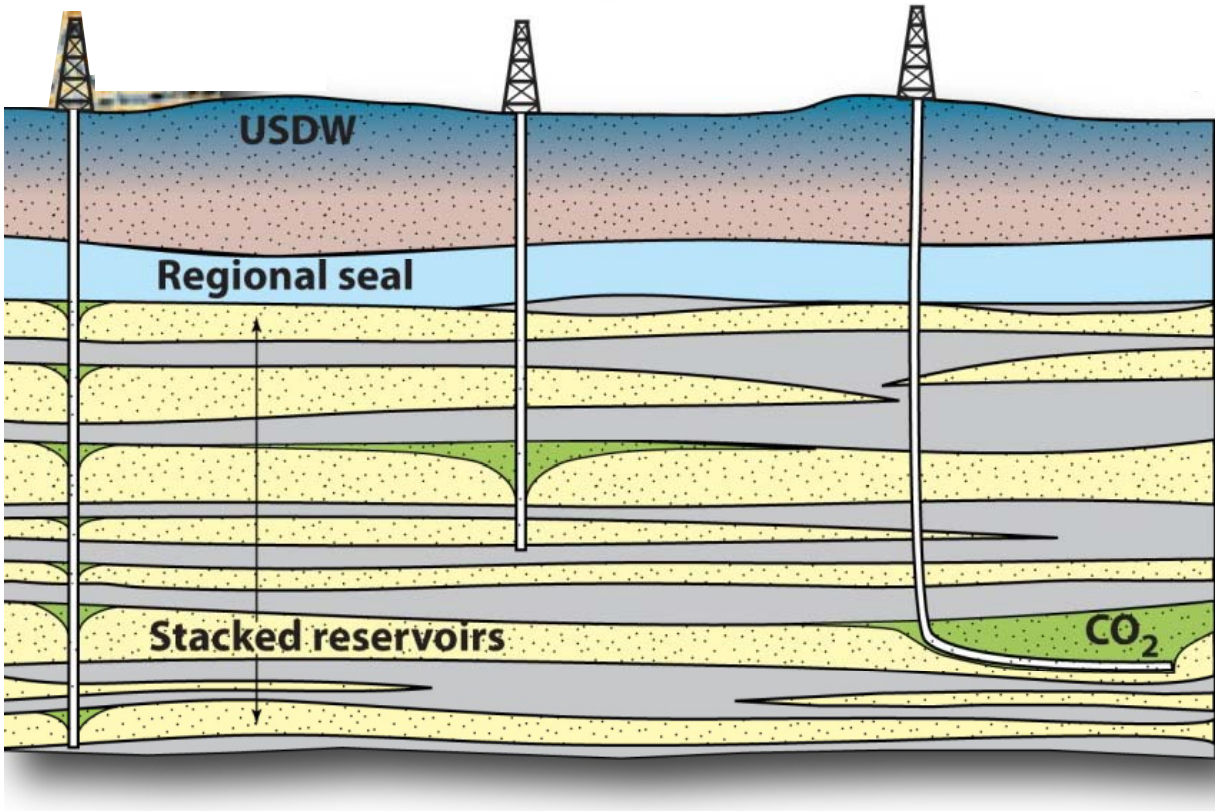


Figure by Jack C. Pashin, Geological Survey of Alabama, 2009.

Assurance of seal layer integrity is a key element in the process of gaining the confidence of plant managers, regulators, investors, and the public in geologic sequestration.

Project Objectives

- Evaluation of the sealing capacity of caprocks intended to serve as barriers to migration of CO_2 sequestered in geologic formations.
- Education and training of undergraduate and graduate students, through independent research on geologic sequestration.
- Education, through an advanced undergraduate/graduate level course on coal combustion and gasification, climate change, and carbon sequestration.
- Simulation of CO_2 migration and trapping in storage reservoirs and potential for seepage through seal layers.

Project Funding

Total Project Cost: $ 344,941

DOE Share: $ 299,941

Non-DOE Cost Share: $ 45,000

Cost Share Provider: Southern Company

Highlights of Project to Date

- 25 students completed the first offering of the course on coal combustion and gasification, climate change, and carbon sequestration, Fall 2010.
- Senior/Key Co-Investigator Richard Esposito defended his dissertation, entitled, "Business models for commercial-scale carbon dioxide sequestration; with focus on storage capacity and enhanced oil recovery in Citronelle Dome," and received the Ph.D. in Interdisciplinary Engineering, December 2010.
- Simulation of CO_2 migration in the Middle Donovan Saline Formation, Citronelle Dome, Southwest Alabama, using the TOUGH2, ECO2N, TOUGHREACT software suite from LBNL (K. Pruess, T. Xu, and coworkers).
- Simulation of permeability reduction by sodium chloride on dry-out of brine by supercritical CO_2.
- Testing begun on shale seal layer core collected by the Southeast Regional Carbon Sequestration Partnership (SECARB) at its test site in the Black Warrior Basin of Alabama.

Tasks – Overview

Task No.	Task Description	Task Duration	Task Funding
1	Project Management and Planning	12/01/2009 – 11/30/2012	$ 30,171[a]
2	Seal Layer Integrity Evaluation	12/01/2009 – 09/30/2012	$ 27,480
3	Student Training through Research	12/01/2009 – 11/30/2012	$206,640
4	Student Training through Formal Course Work	03/01/2010 – 11/30/2012	no cost[b]
5	Simulation of CO_2 Migration and Trapping in Storage Reservoirs and Seepage through Seal Layers	12/01/2009 – 11/30/2012	note c
6	Technology Transfer and Reporting	12/01/2009 – 02/28/2013	$ 35,650

a. Includes time spent by the PI advising and supervising students.
b. Development of new courses and teaching are covered by the State, the School of Engineering, and the Department.
c. Time spent by students on simulation work is included in their stipends; time spent by the PI is included in Project Management.

Project Schedule

Tasks	Planned Completion	Actual Completion
Task 1.1. Project Management Plan	3/26/2010	1/19/2010
Task 2.1. Assemble the experimental apparatus	1/31/2011	1/31/2011
Task 2.2. Collection of Cap Rock, Brine and CO_2	8/31/2011	
Task 2.3. Measurements of Displacement Pressure and Permeability	8/31/2011	
Task 2.4. Evolution of Cap Rock Properities in the Presence of Carbon Dioxide	9/30/2012	
Task 3.1. Sequestration Research by Undergraduates	11/30/2012	
Task 3.2. Research on Geological Sequestration by Master's Degree Students	11/30/2012	
Task 3.3. Research on Geologic Sequestration by Doctoral Students	11/30/2012	
Task 4.1. Develop New Lecture Course on Coal Combustion and Gasification, Climate Change, and Carbon Sequestration	8/20/2010	8/18/2010
Task 4.2. First Offering of New Lecture Course, Fall 2010	12/15/2010	12/15/2010
Task 4.3. Second Offering of New Lecture Course, Fall 2012	11/30/2012	
Task 5.1. Calculations of CO_2 storage capacity and injectivity	8/31/2010	4/3/2010
Task 5.2. Simulation of CO_2 migration	3/31/2011	
Task 5.3. Calculation of CO_2 pressures under seal layers	10/31/2011	
Task 5.4. Simulation of CO_2 seepage in the absence of chemical reactions	5/31/2012	
Task 5.5. Simulation of CO_2 seepage in the presence of chemical reactions	11/30/2012	

Discussion – Task 2: Seal Layer Integrity Evaluation

Michael Hannon, Aaron Lamplugh, Richard Esposito, and Peter Walsh

- Caprock samples from:

  SECARB Black Warrior CO_2 Storage Project
  Montana State University, Advanced CO_2 Leakage Mitigation
  SECARB Phase II CO_2 Storage Pilot, Mississippi Power Plant Daniel
  SECARB Phase III 25-MW CCS Demo, Alabama Power Plant Barry

- Plan:

  Porosity by imbibition
  Permeability using N_2 and CO_2
  Minimum capillary displacement pressure using brine and CO_2

- Problem:

  Separation of shale samples by water, when attempting to measure their porosity by imbibition.

- Measurements recently begun

Discussion – Task 3: Student Training through Research

Richard Esposito, Konstantinos Theodorou, Michael Hannon, Aaron Lamplugh, Peter Walsh

- **Richard Esposito** defended his dissertation, entitled, "Business models for commercial-scale carbon dioxide sequestration; with focus on storage capacity and enhanced oil recovery in Citronelle Dome," and received the Ph.D. in Interdisciplinary Engineering, December 2010.
- **Konstantinos Theodorou** is leading the work on simulation of CO_2 migration and trapping using the TOUGH2, ECO2N, and TOUGHREACT simulation programs from LBNL.
- **Michael Hannon** and **Aaron Lamplugh** are leading the set-up of equipment and measurements of porosity, permeability, and minimum capillary displacement pressure of caprocks.
- Problem: There have been few outstanding candidates interested in the research topic among our applicants for the Master's Degree in Mechanical Engineering. The plan was to have two master's students, two doctoral students, and one undergraduate student working on the project. During the year just completed, there were three doctoral students and one undergraduate.
- Task is 42% complete (15 mo/36 mo).

Discussion – Task 4: Student Training through Formal Course Work

Peter Walsh, Richard Esposito, Michael Hannon, Aaron Lamplugh,
and 23 other graduate and undergraduate students

- Advanced undergraduate/graduate course, entitled "Combustion" offered Fall 2010.
- Focused on coal combustion and gasification for electric power generation, including carbon sequestration, climate change, and energy resources.

Energy resources and utilization:	2	classes
Coal combustion (air and oxygen):	13	"
Gasification and IGCC:	2	"
Control of NO_X, SO_X, and PM:	2	"
CO_2 and greenhouse effect:	2	"
Carbon capture and storage:	3	"
Reviews and exams:	6	"

- Guest lecture by Richard Esposito on CCS research, development, demonstration, and commercialization by Alabama Power, Mississippi Power, and Southern Company, including work at the National Carbon Capture Center.
- Field trip to 2640 MW(electric) Alabama Power Plant Miller.
- Favorable student ratings, 4.93/5.00. Comment from a student in her application to graduate school: "I was excited to learn that my interest in combustion products, their effects on the atmosphere, and methods of capturing them, could be turned into a career in science ...."
- Task is 50% complete. Course to be offered again in Fall 2012.

Discussion – Task 4: Student Training through Formal Course Work (continued)

- Problem: Presentation of the Greenhouse Effect.

  Simple model based on an energy balance on Earth:

  Input = (1 - Albedo)(Solar insolation)(Earth's cross section area)

  Output = (Emissivity)(Stefan-Boltzmann constant)(Earth's surface area)(T_{earth}^4 - T_{space}^4)

  Albedo = 0.3, Emissivity = 0.64, Insolation = 1366 W/m^2, T_{space} = 3 K

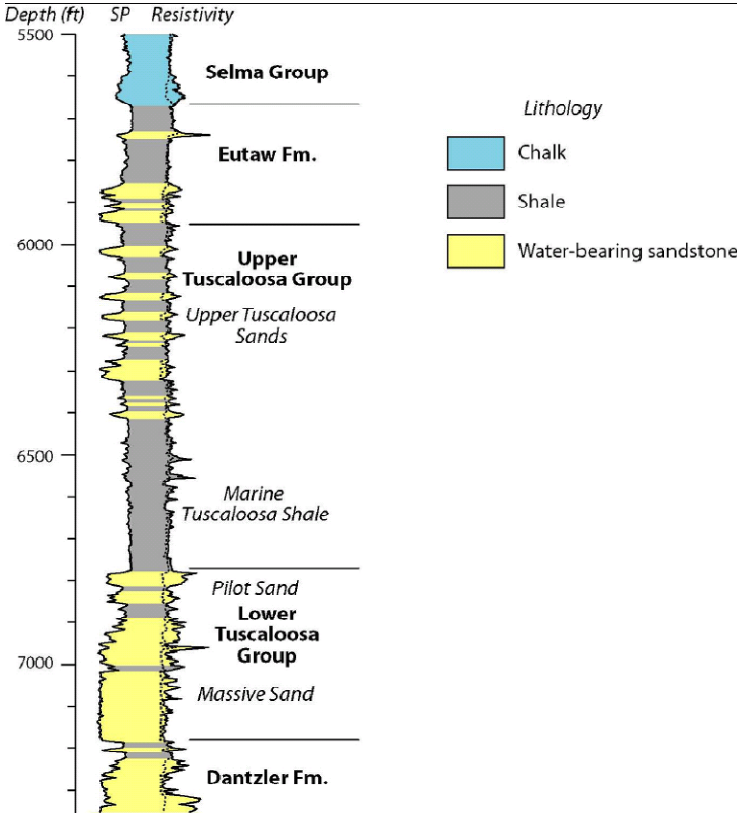
  T_{earth} = 285 K

  This relation can be used to show the sensitivity of the steady average temperature to changes in albedo, emissivity, and insolation, but it doesn't connect changes in albedo or emissivity to the volume fractions of greenhouse gases in the atmosphere.

  Can it be done, approximately but quantitatively, without spending the whole semester on radiative transfer? (e.g. J. Lenoble, *Atmospheric Radiative Transfer*, A. DEEPAK Publishing, Hampton, VA, 1993, 532 pp.)

Discussion – Task 5: Simulation of CO_2 Migration and Trapping in Storage Reservoirs and Seepage through Seal Layers

Konstantinos Theodorou, Richard Esposito, Corey Shum, and Peter Walsh



Alabama Power Plant Barry, 1500 MW.
10 miles from Citronelle.
Coal-fired units produce 10-12 million tons CO_2/year.
Citronelle could provide 45 years of storage.

Estimate of CO_2 Storage Capacity in Citronelle Dome*

Eutaw and Upper Tuscaloosa Sands:	150 - 600 million tons
Lower Tuscaloosa, Pilot Sand:	40 - 160 million tons
Lower Tuscaloosa, Massive Sand:	200 - 790 million tons
Middle Donovan Sands:	24 - 100 million tons
Donovan oil-bearing Sands:	115 - 460 million tons
Total:	**500 - 2000 million tons**

*R. A. Esposito, J. C. Pashin, and P. M. Walsh, *Environmental Geosciences 15*, **2008**, 53-62.

Discussion – Task 5: Simulation of CO_2 Migration and Trapping (continued)

Konstantinos Theodorou and Peter Walsh

Estimate of the critical height of the column of CO_2 that caprock can "support" (Berg, 1975)*

Difference in capillary pressures between pore throats in caprock and pores in the saline formation *vs.* the buoyant force on the column of CO_2:

$$\text{Critical Height} = \frac{\frac{2\gamma}{g}\left[\frac{1}{r_{t,cap}} - \frac{1}{r_{p,res}}\right]}{\rho_w - \rho_{CO_2}}$$

γ	interfacial tension between brine and CO_2 = 0.035 N/m (rough estimate)
$r_{t,cap}$	radius of pore throats in the caprock = 0.15 µm
$r_{p,res}$	radius of pores in the reservoir rock = 5 and 15 µm
g	acceleration due to gravity = 9.8 m/s^2
ρ_w	density of brine = 1000 kg/m^3
ρ_{CO_2}	density of carbon dioxide = 647, 702, and 715 kg/m^3, depending on depth

Estimates of the critical CO_2 column heights ranged from 130 to 160 m, greater than the thickness of any of the saline formations under consideration for CO_2 storage in Citronelle Dome.

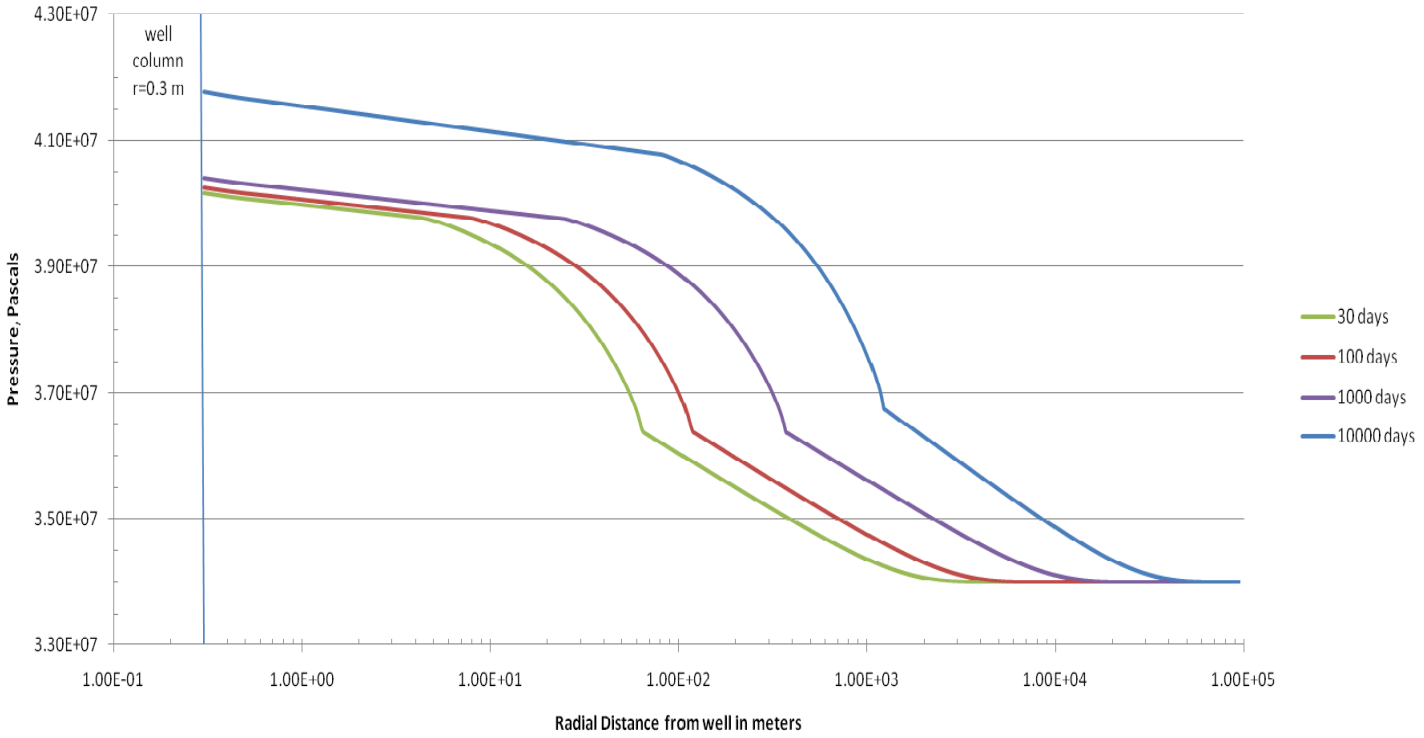
*R. R. Berg, Capillary Pressures in Stratigraphic Traps, *AAPG Bulletin* **1975**, *59* (6), 939-956.

Discussion – Task 5: Simulation of CO_2 Migration and Trapping (continued)

Konstantinos Theodorou

TOUGH2 and TOUGHREACT Software Packages for simulation of CO_2 injection, migration, and trapping in saline formations, with the ECO2N Module for fluid properties. Lawrence Berkeley National Laboratory (Pruess et al., 1999; Xu et al., 2004; Pruess and Spycher, 2006)

Pressure vs. radial distance and time, CO_2 injection at the rate of 346 tonnes per day into a single well in the Middle Donovan saline formation in Citronelle Dome.



Task is 30% complete

Project Milestones

Milestone	Planned Completion Date	Actual Completion Date
1. HQ Milestone: Project Kickoff Meeting	3/31/2010	1/14/2010
2. HQ Milestone: Educational Program Instituted	6/30/2010	4/26/2010
3. HQ Milestone: Semi-Annual Progress Report	9/30/2010	7/30/2010
4. HQ Milestone: Yearly Review Meeting	3/31/2011	2/23/2011
5. HQ Milestone: Yearly Review Meeting	3/30/2012	
6. Revise initial Project Management Plan	3/26/2010	1/19/2010
7. Complete the assembly of the experimental apparatus	1/31/2011	1/31/2011
8. Complete the measurements of permeability and displacement pressure	8/31/2011	
9. Complete the development of new lecture course	8/20/2010	8/18/2010
10. Completion of first offering of new lecture course	12/15/2010	12/15/2010
11. Completion of second offering of new lecture course	11/30/2012	
12. Completion of the calculation of storage capacity and injectivity of reservoir	8/31/2010	4/3/2010
13. Completion of CO_2 migration simulation	3/31/2011	
14. Simulation of CO_2 seepage in the absence of chemical reactions	5/31/2012	
15. Simulation of CO_2 seepage in the presence of chemical reactions	11/30/2012	

Anticipated Efforts for the Coming Year

- Measurements of permeability and minimum capillary displacement pressure of the caprock samples.
- Complete the simulation of CO_2 migration and trapping.
- Complete the calculation of CO_2 pressures under seal layers.
- Begin work on the simulation of capacity and integrity of seal layers.

Investigators' Contact Information

Please address questions and suggestions, or interest in collaboration, to:

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